Adapting ICOLL Estuary Management Plans for Climate Change

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1.0 Introduction

Cardno Lawson Treloar was engaged by Wollongong City Council (WCC) to undertake an assessment of the likely impacts of climate change on Wollongong's estuaries and consider the implications for current and future estuary management practices that arise as a result of these climatically-induced changes in estuarine character. The major focus of the study was the protection of biodiversity and ecological values rather than built assets.

1.1 Background

The Wollongong Local Government Area (LGA) coastline is characterised by a number of estuaries, most of them small creeks, many of which are only intermittently open to the sea. These are referred to as Intermittently Closed and Open Lakes and Lagoons (ICOLLs). In accordance with the NSW Government Estuaries Policy, Estuary Management Plans for all of the key estuaries and Entrance Management Policies for two of the flood-critical estuaries have been prepared by Council to provide a strategic framework for the ongoing management of these estuaries.

The Estuary Management Plans involved a detailed assessment of the ecological, social and hydrological impacts of a large number of management options, including opening the creeks at various water levels, to derive a set of management actions to conserve and protect the estuaries into the future.

However, these Estuary Management Plans were developed for current climatic conditions and did not fully consider the potential long-term impacts of climate change on estuarine processes. This project aimed to assess the likely impacts of climate change on estuary processes, including tidal exchange, entrance condition, water quality and biodiversity (**Sections 3** and **4**). Based on the outcomes of the assessment, the existing Estuary Management Plans and Policies were subjected to a sustainability review (**Section 5**).

2.0 Study Context

2.1 The Study Area

The study area comprises the tidal waterways, foreshores, surrounding open space and adjacent lands (up to the 5 mAHD contour) of the estuaries within the Wollongong LGA, including (from north to south):

- Hargraves Creek,
- Stanwell Creek,
- Stoney Creek,
- Flanagans Creek,
- Hewitts Creek,
- Tramway Creek,
- Slacky Creek,
- Whartons Creek,
- Collins Creek,
- Bellambi Gully,
- Bellambi Lagoon,
- Towradgi Creek,
- Fairy Creek (including the Towradgi Arm), and
- Tom Thumb Lagoon.

The location of these creeks is shown in **Figure 2.1**. Lake Illawarra, which is shared between WCC and Shellharbour City Council and is managed by the Lake Illawarra Authority, has not been incorporated into this assessment.

The Illawarra Escarpment runs parallel with the coast through the Wollongong LGA and therefore much of the development that has occurred has been in the coastal strip. In general, the escarpment is closer to the coast in the northern part of the LGA and some of the creeks located in this portion of the study area drop down to the sea along relatively steep slopes (e.g. Stoney Creek). Further to the south, the escarpment is further to the west and the coastal lands are generally flatter and more typical of coastal floodplain areas.

The small size of the catchments draining to these areas means that the creeks are generally quite small and maintain on average relatively small waterbodies. In general, the catchments in the southern portion of the study area are subject to more intensive land use, whereas those in the northern portion of the study area have higher proportions of undeveloped bushland and lower development densities. The most significantly impacted estuary with respect to human activities is Tom Thumb Lagoon, which drains into Port Kembla. This estuary is permanently connected to Port Kembla (i.e. it is not an ICOLL).

Figure 2.1: Study Area

2.2 Existing Estuary Management Plans and Policies

A brief overview of each of the Estuary Management Plans and Policies is provided below.

2.2.1 Fairy, Towradgi and Hewitts/Tramway Creeks Estuary Management Study and Plan

The *Estuary Management Study and Plan for Fairy, Towradgi, Hewitts and Tramway Creeks* (Cardno, 2005) applies to those areas comprising the tidal waterways, foreshore, surrounding open space and adjacent lands of Fairy Creek, Towradgi Creek and Hewitts/Tramway Creeks.

The values, significance and issues associated with each of these four estuaries are outlined in the Management Study and Plan (Cardno, 2005). A series of options were considered to address the identified management issues. These options were then subjected to a cost:benefit analysis to select a sub-set of suitable management actions for implementation. The Plan identified a total of 65 management actions for implementation at an estimated total capital cost of $1.9 million and estimated annual ongoing costs of $440,000 (Cardno, 2005).

2.2.2 Fairy and Towradgi Lagoons Entrance Management Policies

Two of the management actions that form part of the Plan described in **Section 2.2.1** (Cardno, 2005) recommended the development of Entrance Management Policies for Fairy and Towradgi lagoons. Council subsequently implemented these actions through the development of the *Fairy Lagoon Entrance Management Policy* (Cardno, 2007a) and the *Towradgi Lagoon Entrance Management Policy* (Cardno, 2007b).

As with all ICOLLs, the behaviour of the lagoon entrance (i.e. the berm) can significantly impact on the water level, water quality and ecology of Fairy and Towradgi Lagoons. During extended periods of entrance closure and heavy rainfall, water levels in the lagoons may pose a threat to assets, and while the lagoon would typically naturally breakout under these conditions, neighbouring properties may be subject to inundation before this occurs, putting substantial pressure on Council to mechanically open the entrance for flood mitigation reasons.

In order to manage flood risk, the two Entrance Management Policies (Cardno, 2007a and b) both provide a trigger level of 1.6 mAHD, at which point the entrance should be opened, dependent upon ongoing rainfall in the catchment and the current berm height. Due to the fast response in lagoon water levels to rainfall in the catchment, the alert trigger level is set at 1.4 mAHD.

2.2.3 Estuary Management Plan for Several Wollongong Creeks and Lagoons

The *Estuary Management Study and Plan for Several Wollongong Creeks and Lagoons* (GHD, 2007) applies to those areas comprising the tidal waterways, foreshores, surrounding open spaces and adjacent lands of the following creeks and lagoons (from north to south):

- Hargraves Creek,

- Stanwell Creek,
- Stoney Creek,
- Flanagans Creek (including Thomas Gibson Creek),
- Slacky Creek,
- Whartons Creek,
- Collins Creek,
- Bellambi Gully (including Farrahars Creek catchment),
- Bellambi Lagoon, and
- Tom Thumb Lagoon.

A similar process to that conducted by Cardno Lawson Treloar (2005) was conducted by GHD (2007). The values, significance and issues associated with all 10 of the creeks and lagoons were outlined in the Management Study and Plan (GHD, 2007). A series of options were considered to address the identified management issues. These options were then subjected to a cost: benefit analysis to select a sub-set of suitable management actions for implementation.

The Plan identified a total of 238 management actions for implementation across the entire study area, with some actions applying to all estuaries and others specific to a particular site, at an estimated total capital cost of $4.2 million and estimated annual ongoing costs of $730,000 (GHD, 2007).

2.3 Key State and Federal Legislation and Policy

Some of the key State and Commonwealth legislation and policy relevant to the project is outlined below. Details of all relevant legislation and policy are provided in the full study (Cardno, 2009).

2.3.1 Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* is the Australian Government's key piece of environmental legislation. It focuses on matters of national environmental significance, with the States and Territories having responsibility for matters of State and local significance.

There are a number of migratory or threatened species identified under the EPBC Act that are associated with coastal wetlands and are likely or known to occur within the Wollongong LGA. There is potential for these species to occur within the study area.

2.3.2 NSW Government Threatened Species Conservation Act 1995

The *Threatened Species Conservation (TSC) Act 1995* identifies and protects species of plants and animals that are threatened to some degree with extinction in NSW. There are a number of Endangered Ecological Communities (EECs) and a few threatened species that are associated with the estuaries within the study area.

2.3.3 NSW Draft Sea Level Rise Policy

In acknowledgement of the fact that sea level rise (SLR) will have significant economic, social and environmental impacts on the coastal zone, the NSW Government released a Draft Sea Level Rise Policy in 2009 outlining their objectives and commitments to communities affected by SLR. In support of this policy statement, the NSW Government has adopted a SLR planning benchmark. The NSW SLR planning benchmark is for an increase above 1990 mean sea levels of 40 cm by 2050 and 90 cm by 2100. Full details are provided in DECC (2009b).

3.0 Impact Assessment Methodology

3.1 Adopted Climate Change Scenarios

Climate change impact assessments typically adopt long-term projections (e.g. 2050 and 2100). Because the current study is concerned with the impacts of climate change as they relate to biodiversity, the focus primarily relates to more frequent events and gradual changes, rather than extreme events. This is considered a more practical approach as it relates to the day to day management of the estuaries as well. For these reasons, the climate change projections adopted for this assessment are for the years 2030, 2050, 2070 and 2100.

The impact assessment provided herein takes as its starting point the assumption of no human intervention (either as mitigation strategies or as adaptation strategies).

3.1.1 Sea Level Rise (SLR)

The SLR projections adopted are shown in **Table 3.1**. The 2009 tidal range has been obtained from the National Tidal Centre, while the 2050 and 2100 values have been used in accordance with SLR projections provided in the *Draft Sea Level Rise Policy Statement* for NSW prepared by DECC (2009a). Due to the absence of SLR projections for 2030 and 2070, the corresponding values have been linearly interpolated based on the 2050 and 2100 projections. It is acknowledged that linear interpolation may not be entirely suitable but is reasonable for the purposes of this assessment.

Table 3.1: Adopted SLR Scenarios (in mAHD)

	2009	2030	2050	2070	2100
MLWS*	-0.59	-0.40	-0.19	0.00	0.31
MSL	0.02	0.23	0.42	0.63	0.92
MHWS	0.63	0.83	1.03	1.24	1.53

*MLWS = Mean Low Water Springs, MSL = Mean Sea Level, MHWS = Mean High Water Springs.

3.1.2 Rainfall and Evaporation

Changes in patterns of rainfall and evaporation are also expected to occur under climate change conditions.

The average annual rainfall for the study area is ~1,320 mm/year, based on a time series of data collected over the period 1970-2008 at the University of Wollongong rainfall gauge (gauge number: 068188) by the Bureau of Meteorology (BoM, 2009).

The nearest weather station that records evaporation rates is the Nowra RAN weather gauge (BoM, 2009), at which evaporation data were gathered over the period 1969-1971. Based on these records, a mean daily pan evaporation rate of 4.7 mm/day was obtained (or ~1.70 m/year).

Projected changes in annual rainfall and evaporation were taken from other sources. Many data sources provide estimates for only 2030 and 2070 or 2050 and 2100, but not all four years. In addition, a review of the available data sources found that projections for annual evaporation were only available for the years 2030 and 2070. Therefore, projected changes in annual evaporation were calculated based on a linear interpolation of the available data. A limitation of this analysis is the assumption that percentage changes in evaporation over time can be approximated to a linear function.

Table 3.2 provides a summary of the values used for each of the four climate change timeframes considered. The source of the data is provided in the final column of the table.

Table 3.2: Projected Changes in Average Annual Rainfall and Average Annual Pan Evaporation under Climate Change Conditions

Climate Change Scenario	Input Parameter	Low Extreme	High Extreme	Data Source
2030	Average Annual Rainfall	-13%	+7%	CSIRO (2007)
	Average Annual Evaporation	+1%	+13%	CSIRO (2007)
2050	Average Annual Rainfall	-20%	+10%	CSIRO and BoM (2007)
	Average Annual Evaporation	+1.5%	+26.5%	Linearly interpolated based on 2030 and 2070 data (CSIRO, 2007)
2070	Average Annual Rainfall	-40%	+20%	CSIRO (2007)
	Average Annual Evaporation	+2%	+40%	CSIRO (2007)
2100	Average Annual Rainfall	-54.6%	+22.8%	Garnaut (2008)
	Average Annual Evaporation	+2.75%	+60.2%	Linearly extrapolated based on 2030 and 2070 data (CSIRO, 2007)

3.2 Physical Impact Assessment Methodology

The physical impact assessment was undertaken by specialist coastal engineers. The assessment methodology consisted primarily of a qualitative, desktop assessment supported by basic calculations where appropriate. Cardno Lawson Treloar have subsequently been engaged by WCC to prepare the *Wollongong Coastal Zone Study*, a coastal hazard study (incorporating geotechnical risk) for the entire LGA. Upon completion of that study, the current study would benefit from a review in light of those findings.

Data obtained from to inform the assessment included:

- Site inspections,
- Recent orthorectified aerial photography,

- GIS and ALS data held by Council,
- Hydrographic survey for Fairy, Hewitts and Towradgi Creeks,
- Water quality data for Stanwell, Stony, Flanagans, Slacky, Bellambi and Towradgi Creeks,
- Wave heights for Port Kembla and Port Jackson (directional, in the case of the latter), and
- Water level records at lagoon gauges at 15 minute intervals.

Data were not available for all estuaries within the study area.

3.2.1 Topographic/Bathymetric Mapping and Standing Water Levels

Light Detecting and Ranging (LiDAR) Aerial Laser Survey (ALS) topographical data was used to estimate water levels and extents of inundation for all of the estuaries in the study area. In an effort to extend the topographic mapping below the water surface where ALS becomes inaccurate, existing hydrosurvey data (where available) were incorporated into the topographical data set in order to provide a more realistic and accurate picture of the combined topography/bed morphology of the estuaries in the study area. However, hydrosurvey data were only available for Fairy, Towradgi and Hewitts Creeks, three of the larger estuaries within the study area.

These data were used to develop a 3D surface of the topography/bathymetry for all the estuaries within the study area. Using the 3D surfaces, observations made during site visits, 2006 orthorectified aerial photography provided by Council, Google Earth and available water level records, the approximate location and height of the berm for each of the estuaries was estimated and translated into GIS (both present and future berm heights as described in **Section 3.2.2**).

Based on these inferred average berm heights, the extent of the average standing water levels (SWLs; berm closed) for each of the estuaries was mapped. The extents were mapped for both present day and for each of the climate change scenarios for comparative purposes.

Tom Thumb Lagoon is the only estuary within the study area that is not an ICOLL and therefore the berm analysis is not relevant to this system and it was assumed that there was no attenuation between sea level rise on the open coast and sea level rise in the estuary.

3.2.2 Sediment Supply and Berm Development Capability

A key component of the assessment is whether or not the entrance berm will be capable of keeping pace with SLR. This process relies on the availability of adequate volumes of sand to contribute to the increase in berm height to be located within the compartment that the ICOLL is located in.

Preliminary calculations of the volume of sand required to build the entrance berm height were undertaken for each of the four climate change scenarios based on a function of the berm width, berm height and SLR estimate assuming a roughly triangular berm formation (in cross section).

The next step was to determine whether this volume of sand represented a significant portion of that held within the entire beach compartment. Preliminary calculations were undertaken to characterise the likely change in the width of the entire beach resulting from the re-working of sand from the beach face into the entrance berm. These calculations were based on a function of the volume of sand required to build the entrance berm, beach length and the depth of closure.

These calculations were prepared for the years 2050 and 2100 for indicative purposes only and the results are generally described in **Section 4**.

3.2.3 Berm Position and Shoreline Recession

Shoreline recession resulting from SLR was assessed due to its effect on the entrance berm position. Where shoreline recession occurs, the berm is predicted to move horizontally in a landward direction.

Shoreline recession calculations were informed by a preliminary assessment based on a modified Bruun Rule approach to account for site specific features of the Wollongong coastline. It is widely considered that the traditional Bruun Rule approach, which is based on the equilibrium beach profile concept, is not valid where particular shoreline features are present (e.g. Cooper and Pilkey, 2004). These shoreline features may include, for example, nearshore rock shelves or underlying rock/clay strata, which are common along the Wollongong coastline.

The Bruun Rule is applied to what is termed the active beach slope, being the slope between the berm level and the closure depth. Closure depth is defined as the seasonal limit of effective seasonal profile fluctuations (Dean, 2001). These site specific features were considered in defining the beach profile for application of the Bruun Rule by limiting the closure depth, thereby steepening the active beach profile.

3.2.4 Water Quality

Existing water quality for the 14 estuaries in the study area was characterised based on the available water quality data. Likely impacts on water quality associated with climate change conditions were inferred based on an understanding of existing water quality, as well as interpretation of the results of the assessment of changes to the entrance characteristics and the water balance undertaken as part of the study.

3.3 Biodiversity Impact Assessment Methodology

After completion of the physical impact assessment, specialist estuarine and coastal ecologists conducted an assessment of the likely impact of those changes in physical estuarine processes on the estuarine ecology.

3.3.1 Literature Review

A literature review was undertaken examining two keys issues:

- The influence of the entrance opening regime on estuarine ecology; and

- Tolerances of estuarine vegetation to inundation with saline waters.

Entrance Opening Regime

One of the key considerations is the tolerance of species to rapid environmental change associated with entrance opening. While some estuarine species may be adapted to a wide range of physical variables, others are not, and rapid changes in estuarine assemblages may occur in response to an entrance breakout event (e.g. Dye and Barros, 2005a).

The other key consideration relating to the entrance opening regime was the physical isolation of ICOLLs, where an open connection to the sea is erratic. This can have significant implications for recruitment, with recruitment depending upon the appropriate timing and duration of opening. An open connection with the sea facilitates the exchange of propagules, larvae and adult fauna (and flora in the case of mangrove and saltmarsh propagules) between estuaries and the sea. This exchange supports estuarine biodiversity by maintaining populations of species, some of which may be marine-dependent for some portion of their life cycle (Millet and Guelorget, 1994). In addition, this process of exchange between estuaries facilitates the recovery or recolonisation of any communities or species that may have been subject to local impacts. In systems such as these, biodiversity is low as only a limited number of highly adapted species are able to tolerate such fluctuations in environmental conditions (Teske and Wooldridge, 2001; Dye and Barros, 2005a and b).

Tolerance to Inundation

The types of vegetation present in the study area, along with its condition and extent, is determined by a range of environmental factors. While estuarine vegetation communities are generally well adapted to the range of environmental conditions characteristic of these environments, species-specific requirements with respect to physio-chemical parameters (e.g. hydrology, salinity, etc.), in combination with inter-specific competition, results in a mosaic of vegetation with discernable zonation patterns. Therefore, changes in these parameters are likely to cause shifts in zonation which may vary over a range of spatial and temporal scales.

Information on the zonation of estuarine vegetation and the tolerance of different species to inundation, with specific consideration of those species found within the study area was used to inform the conclusions of the study.

3.3.2 Biodiversity Benchmarking

The process of biodiversity benchmarking is largely a mapping exercise whereby the key ecological attributes of the estuaries are benchmarked for their current status. In this case, the focus has been on the EECs located around the estuary foreshores and the location of these vegetation communities was mapped in relation to the likely patterns of inundation for each of the estuaries.

The purpose of this mapping exercise is to illustrate the extent to which different communities may be impacted by SLR and also locations to which migration may occur under climate change scenarios. Human constructs that may act as an obstruction to the natural migration processes were identified where possible.

4.0 Impact Assessment Results

The results presented herein are limited to a general discussion. The site specific assessments are provided in detail in the full study (Cardno, 2009). An example of the mapping prepared for the study is provided for Fairy Lagoon in **Figure 4.1**.

The results of the physical impact assessment indicate that for all estuaries, the berm is expected to be able to increase in height relative to SLR, with adequate reserves of sand available within their respective beach compartments to contribute to berm development. The entrance berms are also likely to move laterally in a landward direction due to shoreline recession estimated at roughly:

- 5 – 101m by 2030,
- 15.0 – 20m by 2050,
- 20 - 30m by 2070, and
- 30 – 45m by 2100.

There is generally sufficient accommodation space available for this landward translation of the shoreline, although it will likely result in the loss of open space areas.

The impact of changes in rainfall patterns was more difficult to predict, particularly with respect to estuary water levels, although it is thought that all estuaries will continue to maintain a positive net annual water balance. However, it is considered that the shift away from winter rainfall towards summer rainfall may lead to relatively more breakout events occurring during summer, rather than winter. Where this occurs, the incidence of water column stratification in the warmer summer weather may decline leading to water quality improvements. Stratification events may also decrease due to stronger coastal winds, which are likely to increase bed shear stress and therefore the incidence of mixing and sediment re-suspension, particularly where there is sufficient fetch, i.e. in the larger estuaries.

The key impact relates to the increase in water levels associated with the increase in berm height. In the case of Fairy and Towradgi Lagoons in particular, the impact of rising water levels on flooding of properties will likely require more frequent intervention by Council, thereby increasing the frequency of entrance breakouts.

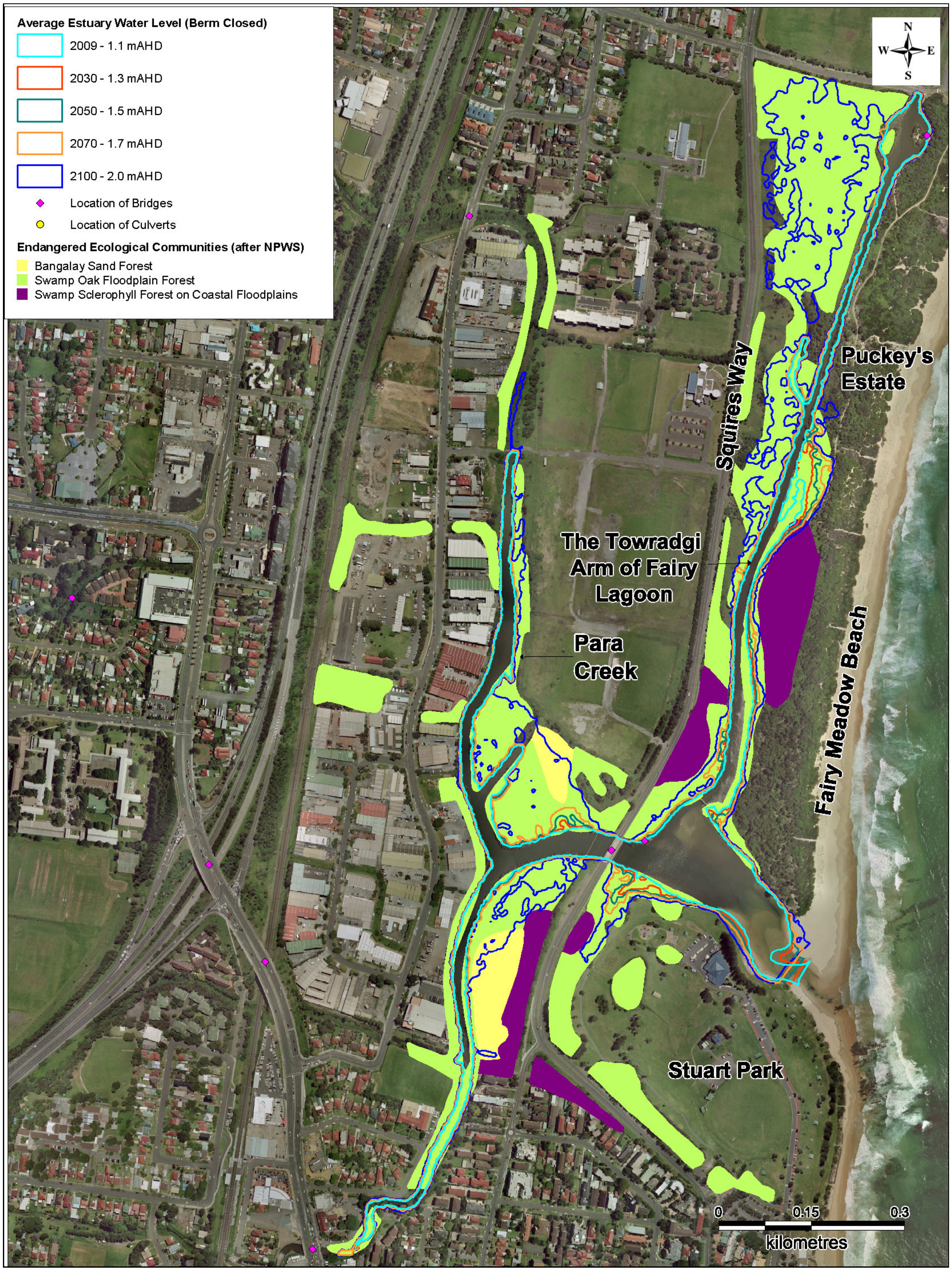

Figure 4.1: Fairy Lagoon

Tom Thumb Lagoon is the exception, being a permanently open system that is located in a sheltered location (Port Kembla Inner Harbour). It has an open entrance and a causeway located approximately 425m upstream that currently limits tidal flushing, although with SLR this will become less of an issue over time resulting in higher water levels and increasing marinisation of the estuary.

Higher water levels will result in more frequent inundation of estuarine vegetation that is currently present. In many cases the estuarine vegetation is likely to be able to migrate landward, although steep banks (e.g. Tom Thumb Lagoon) and human constructs (e.g. those present in Fairy Lagoon, Towradgi Lagoon and Bellambi Lake) may limit migration in some locations. The change in the inundation regime is also likely to favour some species rather than others, which may result in a shift in the species assemblages within the dominant vegetation communities.

5.0 Review of Estuary Management Plans and Policies

As outlined earlier, WCC has advanced the estuary management planning process such that Estuary Management Plans have been prepared for all 14 estuaries referred to in this study (Cardno, 2005; GHD, 2007). However, these Plans were prepared based on an understanding of estuary processes operating under current climatic conditions, and did not include an explicit analysis regarding the likely changes to these estuary processes under future climate change scenarios.

The issue of sustainability as it relates to the implementation of Estuary Management Plans is particularly important in the context of allocating resources for implementation. Where a management action is deemed to be either unsustainable, or less sustainable in the context of climate change, resources should be directed towards implementing those actions that will ultimately be more sustainable under climate change conditions.

5.1 Entrance Management Policies

The Fairy and Towradgi Lagoons Entrance Management Policies (Cardno, 2007a and b) were developed by Council to manage flood risk in the context of appropriate environmental management in the respective lagoon catchments. These Policies were developed based on an analysis of historical berm heights, water levels and entrance behaviour for current climatic conditions. Under climate change conditions, the rate of rise, berm height and depth of scour is expected to change.

It was determined that the frequency with which the Council is required to break open the entrance may increase due to changing rainfall patterns under climate change conditions. Changes in the total volume of rainfall or berm height will not directly necessitate modification of the policies as the current foreshore property levels (primarily ground levels but also floor levels) are the key drivers for the policies. These properties will become inundated above the current trigger level of 1.6 mAHD unless they are elevated or relocated to higher ground (e.g. as part of the implementation of a floodplain management plan or when a property is re-developed).

However, most sources appear to agree that an increase in rainfall intensity and frequency for rare catchment flood events will likely occur under climate change. Therefore, the key issue is likely to be the increase in the rate of rise of floodwaters.

Where the rate of rise increases, the time available to mobilise the necessary personnel and equipment to conduct a mechanical breakout is reduced. Therefore, it was recommended that in the future, Council may wish to lower the alert level for both Fairy Lagoon and Towradgi Lagoon to provide additional time to mobilise the necessary resources, should mechanical breaching of the berm of these systems be required.

5.2 Estuary Management Plans

For the purposes of the study, Council provided the full list of management actions identified for implementation in both the *Fairy, Towradgi and Hewitts/Tramway Estuary Management Plan* (Cardno, 2005) and the *Estuary Management Plan for Several Wollongong Creeks and Lagoons* (GHD, 2007). Council also provided a list of the status of all actions which outlined whether the action is either remaining (i.e. not yet actioned), underway or complete.

5.2.1 Review Methodology

The methodology by which these existing Management Plans were subjected to review is outlined below:

- Those actions that have already been implemented were identified and removed from the list.
- There were some actions identified by GHD (2007) that would be implemented under the State Government's Floodplain Management Program, as opposed to the Estuary Management Program. These were also deleted from the list of actions.
- The full list of actions from each of the two existing Management Plans was then amalgamated. Where duplications occurred, multiple actions were collapsed into a single management action (where appropriate).

This process resulted in the creation of a master list of management actions for the 14 estuaries of interest.

5.2.2 Recommendations for Additional Management Actions

Having compiled a master list of management actions based on those previously identified in Cardno (2005) and GHD (2007), consideration of additional management actions for inclusion that seek to address the outcomes of the climate change assessment was made. This included consideration of:

- <u>Mitigative Actions</u> – actions aimed at limiting or reducing the impacts of climate change on Wollongong's estuaries before they occur; and
- <u>Adaptive Actions</u> – actions aimed at managing the unavoidable impacts of climate change once they occur.

5.2.3 Climate Change Strategy for Wollongong's Estuaries

All actions outlined in the master list of management actions were then translated into a Climate Change Strategy for implementation by Council, which identifies those estuary management actions that are affected by climate change.

The final Climate Change Strategy consists of a list of 287 management actions of which:

- 56 were either modified or directly adopted from Cardno (2005)
- 206 were either modified or directly adopted from GHD (2007)
- 25 were developed as additional actions as part of this study.

5.0 Conclusions and Recommendations

One of the NSW Coastal Policy's strategic actions is the preparation and implementation by Councils of detailed management plans for estuaries in accordance with the Estuary Management Policy. Wollongong City Council has advanced the Estuary Management Process such that Estuary Management Plans have been prepared for 14 estuaries within the LGA (Cardno, 2005; GHD, 2007). However, the potential impacts of climate change on estuarine processes and on the sustainability of management actions were not fully considered.

This project has sought to address this issue through an assessment of the likely impacts of climate change on estuary processes, including tidal exchange, entrance condition, water balance, geomorphology, water quality and biodiversity. Based on the outcomes of the assessment, the existing Estuary Management Plans and Policies were subjected to a sustainability review and a Climate Change Strategy has been developed.

The Climate Change Strategy comprises a large number of actions for implementation, many of which have been directly adopted from the existing Management Plans, albeit in modified form. A series of further options were recommended to address the ongoing sustainability of estuary management into the future.

This study was limited to partly qualitative assessment by specialist Engineers and Scientists in some cases due to both the high level of uncertainty associated with the climate change projections analysed and the limited available data regarding some estuary processes. The importance of obtaining and collating data is vital to informing ongoing management and is crucial to facilitating an adaptive management response. In addition, it will become increasingly important to monitor estuary processes in order to validate the impact assessment provided herein, and also to identify where interactions are occurring between the impacts of climate change and human activity in the catchment.

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